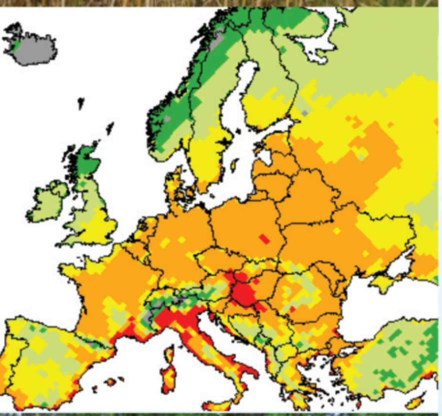
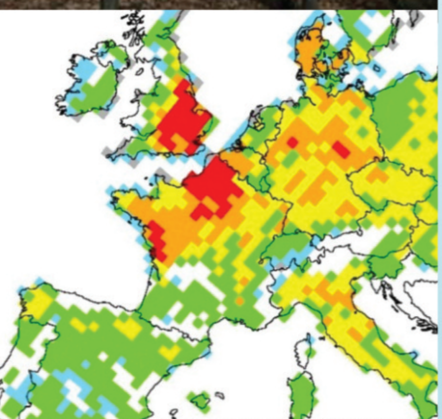






LRTAP
Long-range Transboundary Air Pollution

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Flux-based critical levels of ozone pollution for vegetation

Overview of new developments, 2017

- **Twenty one ozone flux-effect relationships and associated critical levels** are available for science and policy application to assess the risk of ground-level ozone impacts on vegetation (crops, forest trees, (semi-)natural vegetation).
- Calculated ozone fluxes ('Phytotoxic Ozone Dose') provide a **biologically relevant indication** of vegetation and areas at risk from adverse impacts of ozone.
- Calculation of **critical level exceedance** provides an indication of the sufficiency and effectiveness of national, European and global ozone pollution abatement initiatives and policies.

http://icpvegetation.ceh.ac.uk

wge
Working Group on Effects
of the
Convention on Long-range Transboundary Air Pollution

Ozone pollution: Impacts on vegetation

At ground-level, ozone is an air pollutant that has negative impacts on sensitive vegetation, affecting food production and other ecosystem services (Mills et al., 2013*). Here, an overview is provided of the current state of knowledge of **flux-based ozone critical levels for effects of ozone on**:

- Crop yield (quantity and quality);
- Tree biomass;
- Grassland biomass, flower & seed production.

Ozone critical levels for vegetation

Flux-based ozone critical levels for vegetation are the "**cumulative flux of ozone into leaves** above which direct adverse effects on sensitive vegetation may occur according to present knowledge".

Air pollution abatement policies have been developed **in Europe** to reduce emissions of the precursors of ozone, including oxides of nitrogen and non-methane volatile organic compounds:

- ❑ The UNECE Long-range Transboundary Air Pollution (LRTAP) Convention established a multi-pollutant, multi-effect Protocol in 1999 (Gothenburg Protocol), amended in 2012, including abatement of ground-level ozone concentrations.
- ❑ The European Union established the National Emissions Ceilings Directive in 2003 (Directive 2003/35/EC), amended in 2016 (Directive (EU) 2016/2284), setting emission ceilings for ozone precursors.

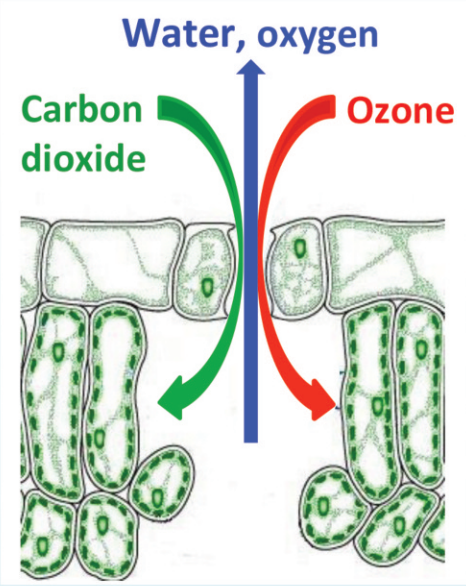
Aim of this brochure

To provide an overview of flux-based ozone critical levels for vegetation for application in ozone risk assessment and provide guidance on which flux-effect relationships and critical levels to use for science and policy application.

For full details of the methodology, see Chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention (http://icpvegetation.ceh.ac.uk).

* Mills et al., 2013. Ozone pollution: Impacts on ecosystem services and biodiversity. ISBN: 978-1-906698-39-3

Modelling the stomatal flux of ozone: Phytotoxic Ozone Dose (POD)



*A schematic showing a cross section through a leaf. Arrows show the uptake of carbon dioxide and ozone, and the release of water and oxygen through leaf pores ('**stomata**').*

Ozone enters the leaf via the same small pores ('stomata') on the leaf surface where carbon dioxide is taken up to enable plant growth, oxygen is released to the atmosphere and water is evaporated (see picture).

The amount of **ozone taken up** ('**stomatal ozone flux**') depends on the opening and closing of the leaf pores, which **varies with leaf age and environmental conditions such as temperature, humidity, light intensity and soil water content**.

The damage to plants is determined by the accumulated hourly 'uptake' of ozone above a threshold flux Y during daylight hours, known as the **Phytotoxic Ozone Dose (POD_Y).** POD_Y is calculated during a specified time or growth period. The DO_3SE model has been developed to calculate POD_Y (http://www.sei-international.org/do3se).

Types of POD_Y and associated critical levels

Two types of POD_Y have been defined:

- **POD_YSPEC:** a plant species (group)-specific POD_Y that requires comprehensive input data and is suitable for detailed risk assessment.
- **POD_YIAM:** a vegetation-type specific POD_Y that requires less input data and is suitable for large-scale modelling, including integrated assessment modelling.

For deriving critical levels or calculating the percentage effect, only effects occurring above a reference POD_Y determined at a constant ozone concentration of 10 parts per billion (ppb) are considered (Ref10 POD_Y), where 10 ppb represents the estimated average 'pre-industrial' ozone concentration.

The percentage effect due to ozone impact should be calculated as follows:

(POD_YSPEC – Ref10 POD_YSPEC) x % reduction per unit POD_YSPEC

Note: For POD_YIAM, a similar calculation should be applied only for crops.

Species-specific flux-based critical levels for detailed assessment of risk of impacts

Species-specific ozone flux models, flux-effect relationships and critical levels have been derived for a number of crop, forest tree and (semi-)natural vegetation species (or group of species). **They can be used at any geographical scale to quantify the degree of risk of ozone impacts to a specific (group of) species**.

Crops: Specifies-specific critical levels (‘POD_6SPEC’)

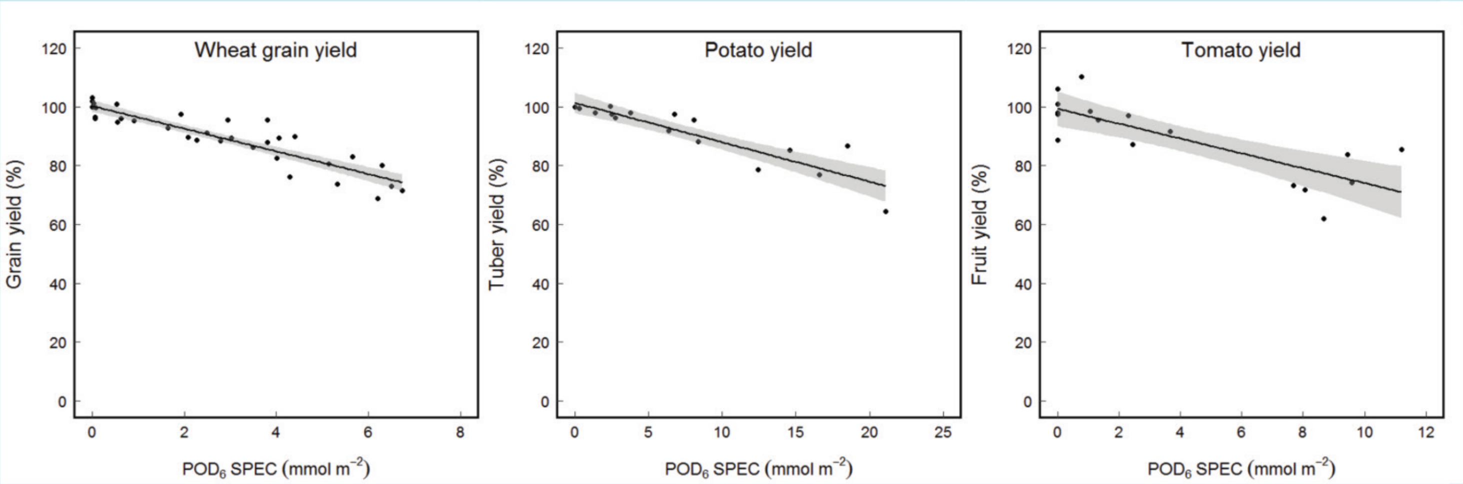
These are available for effects of ozone on wheat yield (using two region-specific flux model parameterisations), tomato (using a Mediterranean parameterisation) and potato (using a parameterisation suitable for continental, boreal and atlantic regions).

Applications for species-specific flux-effect relationships and critical levels for crops (‘POD_6SPEC’)

Species-specific flux-effect relationships and critical levels for crops can be used to quantify negative impacts of ozone on the **security of food supplies**. **They can be used to estimate yield losses, including economic valuations.**

Species-specific flux-based critical levels for crops (‘based on POD_6SPEC’).

Species	Effect indicator	Potential effect at critical level (% reduction)	Critical level (mmol m^{-2})	Potential maximum rate of reduction (% per unit POD_6SPEC)
Wheat	Grain yield	5%	1.3	3.85
Wheat	1000-grain weight	5%	1.5	3.35
Wheat	Protein yield	5%	2.0	2.54
Potato	Tuber yield	5%	3.8	1.34
Tomato	Fruit yield	5%	2.0	2.53
Tomato	Fruit quality	5%	3.8	1.30



Examples of species-specific flux-effect relationships for crops (‘based on POD_6SPEC’).

For details see Chapter 3 of the Modelling and Mapping Manual (http://icpvegetation.ceh.ac.uk)

Forest trees: Species-specific critical levels ('POD_1SPEC')

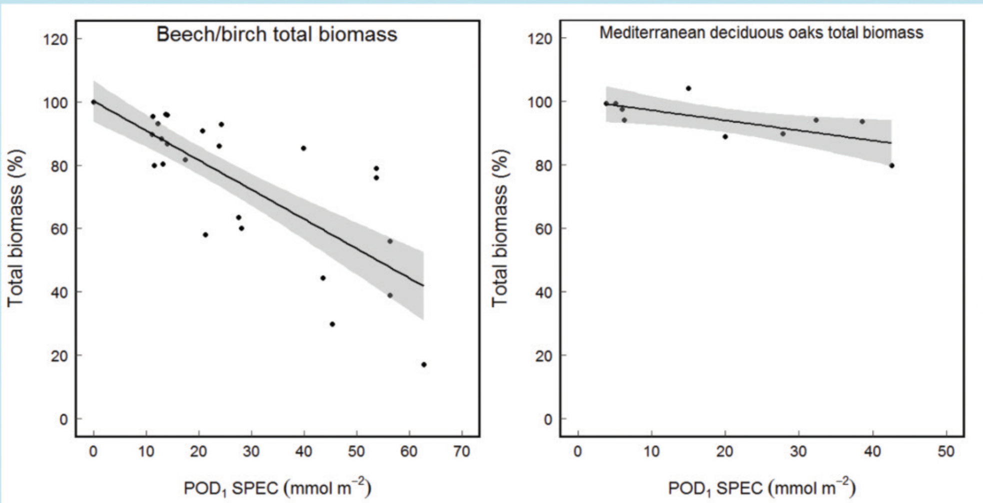
Species-specific critical levels have been derived for beech/birch (combined) and Norway spruce for boreal and continental regions, but they could also be applied to atlantic, steppic and pannonian regions (EEA, 2016*). Species group-specific critical levels are also available for Mediterranean oaks and Mediterranean evergreen species.

Applications for species-specific flux-effect relationships and critical levels for forest trees ('POD_1SPEC')

Species-specific flux-effect relationships and critical levels for forest trees were derived from experiments with young trees. They can be used to quantify negative impacts of ozone on the **annual growth of the living biomass of trees,** and as a starting point for the calculation of impacts on carbon sequestration and tree diversity.

Species-specific flux-based critical levels for trees ('based on POD_1SPEC').

Species	Effect indicator	Potential effect at critical level (% reduction)	Critical level (mmol m^{-2})	Potential maximum rate of reduction (% per unit POD_1SPEC)
Beech/birch	Whole tree biomass	4%	5.2	0.93
Norway spruce	Whole tree biomass	2%	9.2	0.22
Mediterranean deciduous oaks	Whole tree biomass	4%	14.0	0.32
Mediterranean deciduous oaks	Root biomass	4%	10.3	0.45
Mediterranean evergreen	Above-ground biomass	4%	47.3	0.09



Examples of species-specific flux-based critical levels for trees ('based on POD_1SPEC').

* http://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3

For details see Chapter 3 of the Modelling and Mapping Manual (http://icpvegetation.ceh.ac.uk)

(Semi-)natural vegetation: Species-specific critical levels (‘POD_1SPEC’)

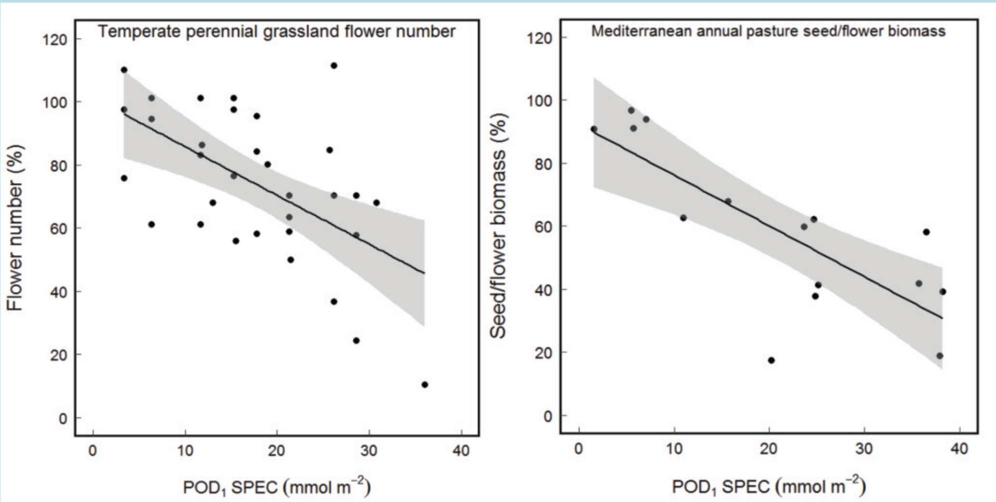
Species group-specific critical levels are available for temperate perennial grasslands found in boreal, atlantic and continental regions (they can also be applied to steppic and pannonian regions) and for Mediterranean annual pastures. Less than 2% of (semi-) natural vegetation species have been tested for ozone-sensitivity.

Applications for species-specific flux-effect relationships and critical levels for (semi-)natural vegetation (‘POD_1SPEC’)

Species group-specific flux-effect relationships and critical levels for (semi-) natural vegetation were derived from experiments with ozone-sensitive species. They can be used to quantify the negative impacts of ozone on **biomass or reproductive capacity** and as a starting point for the calculation of impacts on carbon sequestration and plant biodiversity.

Species group-specific flux-based critical levels (semi-)natural vegetation (‘based on POD_1SPEC’).

(Group of) species	Effect indicator	Potential effect at critical level (% reduction)	Critical level (mmol m^{-2})	Potential maximum rate of reduction (% per unit POD_1SPEC)
Temperate perennial grassland	Above-ground biomass	10%	10.2	0.99
Temperate perennial grassland	Total biomass	10%	16.2	0.62
Temperate perennial grassland	Flower number	10%	6.6	1.54
Mediterranean annual pasture	Above-ground biomass	10%	16.9	0.85
Mediterranean annual pasture	Flower/seed biomass	10%	10.8	1.61



Examples of species group-specific flux-based critical levels for (semi-)natural vegetation (‘based on POD_1SPEC’).

For details see Chapter 3 of the Modelling and Mapping Manual (http://icpvegetation.ceh.ac.uk)

Vegetation-type ozone flux-based critical levels for assessing risk in large scale and integrated assessment modelling ('POD_YIAM')

Vegetation-type, simplified ozone flux models, flux-effect relationships and critical levels have been derived for crops, forest trees and (semi-)natural vegetation. **Separate parameterisations for the flux models are to be used for Mediterranean and non-Mediterranean areas,** with separate critical levels derived for forest trees and (semi-) natural vegetation.

Applications for simpler vegetation-type flux-effect relationships and critical levels ('POD_YIAM')

Vegetation-type flux models are simpler than species-specific models and have been developed specifically **for use in large-scale integrated assessment modelling,** including for scenario analysis and optimisation runs. The flux-effect relationships and critical levels can be used to assess exceedance of critical levels and/or **quantify the risk of adverse impacts of ozone on the most sensitive vegetation**.

They provide an indicative risk assessment and are less robust than the species-specific flux models. For crops they can be used to calculate the potential maximum yield loss and indicative economic losses. For forest trees and (semi-)natural vegetation, they provide an indicative estimation of environmental cost, but not economic losses. Application in a climate change context or in soil water limited areas is not recommended as key factors such as plant development and soil moisture are not considered.

Vegetation-type flux-based critical levels for crops, forest trees and (semi-)natural vegetation ('based on POD_YIAM').

Vegetation type (POD_YIAM)	Effect indicator	Use to asses risk to	Biogeo-graphical region	Potential effect at critical level (% reduction)	Critical level (mmol m^{-2})
Crops (POD_3IAM)	Grain yield	Grain yield	All	5%	7.9
Forest trees (POD_1IAM)	Whole tree biomass	Annual growth of living biomass	Non-Med.*	4%	5.7
			Med.*	4%	13.7
(Semi-)natural vegetation (POD_1IAM)					
Temperate perennial grassland	Flower number	Vitality of species-rich grasslands	Non-Med.	10%	6.6
Mediterranean annual pasture	Flower/seed biomass		Med.	10%	10.8

* Non-Med. = Non-Mediterranean; Med. = Mediterranean.

For details see Chapter 3 of the Modelling and Mapping Manual (http://icpvegetation.ceh.ac.uk)

Flux-based critical levels for ozone pollution

Using a combination of mathematical modelling and scientific experiments under varying climatic conditions and ozone concentrations, **21 ozone flux-effect relationships and associated critical levels** have been derived for crops, forest trees and (semi-) natural vegetation. In this brochure, a summary is provided of these flux-effect relationships and critical levels. Full details on the methodology can be found in Chapter 3 ('Mapping critical levels for vegetation') of the Modelling and Mapping Manual of the Long-range Transboundary Air Pollution Convention and in associated background documents (see http://icpvegetation.ceh.ac.uk for details).

Calculation of ozone fluxes ('Phytotoxic Ozone Dose') provides a biologically relevant indication of vegetation and areas most at risk from adverse impacts of ozone. Calculation of ozone critical level exceedance provides an indication of the sufficiency and effectiveness of national, European and global ozone pollution abatement initiatives and policies.

This brochure was produced by the Programme Coordination Centre of the ICP Vegetation (http://icpvegetation.ceh.ac.uk). The ICP Vegetation is an International Cooperative Programme reporting on effects of air pollution on vegetation to the Working Group on Effects of the UNECE Convention on Long-range Transboundary Air Pollution.

March, 2017

Acknowledgements

We thank Håkan Pleijel (University of Gothenburg; Chair of the crops working group), Patrick Büker (SEI-York, University of York; Chair of the forest trees working group) and Ignacio González-Fernández (CIEMAT, Spain; Chair of the (semi-)natural vegetation working group) and all the members of these working groups for their contribution to the further development of the ozone flux-based methodology and the establishment of flux-based critical levels.

We thank the UK Department for Environment, Food and Rural Affairs (Defra, contract AQ0833), the UNECE (Trust Fund) and the Natural Environment Research Council (NERC) for financial support of the Programme Coordination Centre of the ICP Vegetation.

Photos: Shutterstock, UK and CEH staff (F. Hayes, H. Lowther, J. Chaplow, I. Simpson).
Flux-effect relationship figures were produced by Katrina Sharps (CEH, Bangor), using data supplied by ICP Vegetation participants.

For further information, please contact:

Gina Mills, Harry Harmens, Felicity Hayes
ICP Vegetation Programme Coordination Centre
Centre for Ecology & Hydrology
Deiniol Road, Bangor, Gwynedd, LL57 2UW, UK
Tel: +44 (0) 1248 374500
Email: gmi@ceh.ac.uk; hh@ceh.ac.uk; fhay@ceh.ac.uk

This brochure and other publications are available at
http://icpvegetation.ceh.ac.uk

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